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Certificate
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Applicant	:	Carneal, et al.
U.S. Patent No.	:	6,982,969 (U.S. Application. No. 09/407,645)
Issue Date	:	January 3, 2006
For	:	METHOD AND SYSTEM FOR FREQUENCY SPECTRUM RESOURCE ALLOCATION

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Gregory A. Hermanson, Reg. No. 53,018

Transmitted herewith for filing and consideration in the above-referenced application are the following documents:

(X) Certificate of Correction in 1 page.

(X) Pertinent Pages of the issued patent (9 pages).

As the errors were incurred at least in part due to the fault of the U.S. Patent and Trademark Office, no fee is required.

The Commissioner is hereby authorized to charge any fees which may be required, now or in the future, or credit any overpayment to Account No. 11-1410.

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UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 6,982,969
APPLICATION NO. : 09/407,645
ISSUE DATE : January 3, 2006
INVENTOR(S) : Carneal et al.

It is certified that errors appear in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On page 1 of the patent at column 2 (Other Publications), line 4, line 4, delete "pps." and insert --pp.-- therefore;

On page 3 of the patent at column 1 (Other Publications), line 4, delete "pps." and insert --pp.-- therefore;

On page 3 of the patent at column 1 (Other Publications), line 9, delete "pps." and insert --pp.-- therefore;

At column 5, line 54, delete "Is" and insert --is-- therefore;

At column 6, line 37, delete "parameters" and insert --parameter-- therefore;

At column 6, line 49, delete "330" and insert --300-- therefore;

At column 7, line 36, after "of" insert --the demand--;

At column 9, line 10, delete "lest" and insert –least-- therefore;

At column 12, line 57, delete "of" and insert --or-- therefore;

At column 13, line 5, delete "date" and insert --data-- therefore;

At column 18, delete "reallocate" and insert --re-allocate-- therefore;

At column 20, delete "or" and insert --on-- therefore;

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(12) **United States Patent**
Carneal et al.

(10) **Patent No.: US 6,982,969 B1**
(45) **Date of Patent: Jan. 3, 2006**

(54) **METHOD AND SYSTEM FOR FREQUENCY SPECTRUM RESOURCE ALLOCATION**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(58) **Field of Classification Search** 370/328, 370/329, 330, 341, 343, 344, 478, 480, 484, 370/468, 477; 455/422, 450, 451, 452, 453, 455/507, 509, 517

See application file for complete search history.

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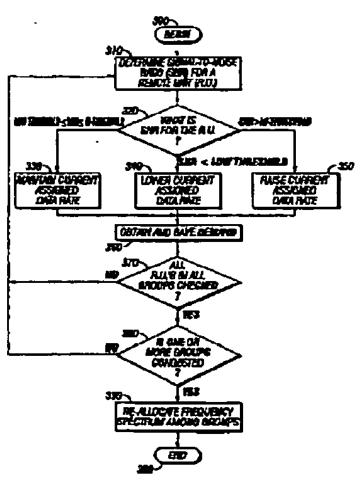
(57) **ABSTRACT**

A system and method for allocating one or more portions of the frequency spectrum among a plurality of radio frequency (RF) transmitters and/or receivers. The system comprises a hub station that dynamically allocates the frequency spectrum in response to demand of the plurality of RF transmitters and/or receivers. Based on the demand, the hub station analyzes the state of performance of one or more groups of RF transmitters and/or receivers, and optimizes utilization of the assigned frequency spectrum.

30 Claims, 10 Drawing Sheets



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multiple remote units. The system **200** may apply TDMA, FDMA, any other access technique, or a combination of access techniques to implement the invention. The number of stations in the system **200** is only illustrative and, hence, the system **200** may comprise any desired number of hub and remote stations.

The remote units are categorized into two or more operational groups of remote units (sometimes referred to as "camps" of remote units) based on the assigned data rate of each remote unit. In one embodiment, the system **200** comprises three groups of remote units: Group **32**, Group **64**, and Group **128**. Group **32** includes one or more remote units that operate at a data rate of 32 kbps, Group **64** includes one or more remote units that operate at a data rate of 64 kbps, and Group **128** includes one or more remote units that operate at a data rate of 128 kbps. Typically, the hub station **210** determines and communicates the assigned data rate to each remote unit. For example, the hub station **210** may assign a data rate of 32 kbps to the remote units **212**, **214**, and **216**, thereby placing these remote units in Group **32**. Similarly, the hub station **210** may assign a data rate of 64 kbps to the remote units **232** and **234**, thereby placing these remote units in Group **64**. Finally, the hub station may assign a data rate of 128 kbps to the remote units **252** and **254**, thereby placing these remote units in Group **128**.

The hub station **210** determines and assigns the data rate to each remote unit based on its respective channel condition. The channel condition indicates the ability of the channel to sustain an assigned data rate while still maintaining an acceptable signal performance (e.g., SNR). In one embodiment, the hub station **210** is configured to continuously, or at predetermined time intervals, monitor the channel performance based on signals received from each of the remote units. More particularly, the hub station **210** may measure the SNR over a predetermined time interval to assess channel performance of each remote unit. The hub station **210** compares the measured SNR to predetermined SNR threshold values. The SNR thresholds may comprise a low-threshold value (e.g., 8 dB) and a high-threshold value (e.g., 11 dB). Based on this comparison, the hub station **210** determines whether to change the currently assigned data rate for each remote unit and, consequently, whether to re-categorize the remote unit from one group to another.

For example, if the measured SNR of the signals received from the remote unit **232** falls within the low and high thresholds, the hub station **210** determines that the remote unit **232** is operating at an optimal data rate and, hence, no change of the assigned data rate is necessary. If the measured SNR is above the high-threshold value, the hub station **210** determines that the channel of the remote unit **232** can sustain a higher data rate. Accordingly, the hub station **210** may instruct the remote unit **232** to raise its data rate from 64 kbps to a higher data rate, e.g., 128 kbps. If, on the other hand, the measured SNR is below the low-threshold value, the hub station **210** determines that the channel utilization of the remote unit **232** is unacceptable and its presently assigned data rate should be reduced. Accordingly, the hub station **210** may instruct the remote unit **232** to decrease its data rate from 64 kbps to a lower data rate, e.g., 32 kbps. The hub station **210** may repeat this process to optimize channel utilization for all remote units. In one embodiment, the average transmit power at each remote unit is unaffected and maintained substantially fixed throughout this process.

In addition, the hub station **210** is configured to dynamically allocate portions of the assigned frequency spectrum to the remote units in response to changes in the demand of each remote unit. As used herein, the term "demand" refers

to the amount of information (e.g., data expressed in bits) that a remote unit desires to exchange or transmit at a particular instant of time. Typically, the system **200** uses a channel, such as a reservation channel, on which each remote unit periodically, or when requested, reports or transmits its current demand to the hub station **210**. In one embodiment, the hub station **210** is configured to determine the collective demand of the remote units on a group-by-group basis (hereinafter "aggregate demand"). As will be discussed in greater detail below, based at least in part on the aggregate demand of each of Groups **32**, **64**, and **128**, the hub station **210** determines the portion of the frequency spectrum to be allocated to each of the Groups **32**, **64**, and **128**. By so doing, the hub station **210** continuously reduces congestion and transmission delay of and optimizes the frequency utilization among the groups of remote units.

In one embodiment, it is desirable to check the quality of service (QoS) assigned to each remote unit before determining the aggregate demand of each of the Groups **32**, **64**, and **128**. Generally, QoS may specify a nominal guaranteed throughput level (e.g., amount of data in bits) or data rate (expressed in kbps) for each remote unit. The QoS is typically assigned to each remote unit pursuant to a subscription agreement between the remote unit and the service provider, e.g., owner of the hub station **210**. As used herein, the term "QoS" refers to any one or more criteria that a hub station **210** may use to classify the quality of performance committed or provided to a remote unit.

In general, the hub station **210** may use any communication parameter to allocate one or more portions of the frequency spectrum among the remote units. The communication parameter may include the aggregate demand of a group of remote units, individual demand of a single remote unit, quality of service, channel performance (e.g., SNR or BER measurements), number of remote units in a group, propagation paths (e.g., distance, terrain, etc.), any other parameters that affects performance of the wireless communication system **200**, or any combination of these parameters. As further discussed below, based on the communication parameter, the hub station **210** determines the current or anticipated state of performance of the group of remote units (or a single remote unit) to allocate one or more portions of the frequency spectrum.

FIG. 3 is a flowchart describing the process of determining whether to re-allocate the frequency spectrum among two or more groups of remote units of the system of FIG. 2. As noted above, in one embodiment, the remote units are categorized or distributed among Groups **32**, **64**, and **128**. The process begins at block **300** when the system **200** initiates an algorithm to check channel performance for each remote unit. For example, the algorithm may be implemented using any microprocessor-based instructions, such as conventional firmware, programmed in, or on a device within fast access of the hub station **210**. At block **310**, the system **210** monitors a channel by listening for signals received from a first remote unit (e.g., the remote unit **232**). In one embodiment, each remote unit may transmit signals to the hub station **210** over a predetermined or other available channel during periodic time intervals. The hub station **210** measures the energy of the signal and noise components of the signals arriving from the remote unit **232**. As described above, the hub station calculates the SNR over a predetermined time interval (e.g., 100 milliseconds) for the remote unit **232**.

At the decision block **320**, the hub station **210** determines whether to change currently assigned data rate of the remote unit **232** based on the measured SNR. As noted above, the

hub station **210** is programmed with low (e.g., 8 dB) and high (e.g., 11 dB) threshold values to compare the measured SNR. The range between the low and high thresholds represents sufficient channel performance for the currently assigned data rate. Accordingly, if the measured SNR falls within the low and high thresholds, the process proceeds to block **330** where the hub station **210** maintains the currently assigned data rate for the remote unit **232**. In this case, the process continues to block **370** where the hub station **210** determines if all of the remote units in the group are checked, as described below.

The range of SNR below the low threshold value represents an undesirable channel performance where the noise level is relatively high for the currently assigned data rate. Hence, if the measured SNR falls below the low threshold value, the process proceeds to block **340** where the hub station **210** instructs the remote unit **232** to reduce its currently assigned data rate from 64 kbps to a lower data rate, e.g., 32 kbps. Thus, in such an event, the hub station **210** re-categorizes the remote unit **232** from Group **64** to Group **32**. On the other hand, the range of SNR above the high threshold value represents an inefficient use of the channel where the noise level is relatively low for the currently assigned data rate. Hence, in block **320** if the measured SNR falls above the high threshold value, the process proceeds to block **350** where the hub station **210** instructs the remote unit **232** to increase its currently assigned data rate from 64 kbps to a higher data rate, e.g., 128 kbps. Thus, in such an event, the hub station **210** re-categorizes the remote unit **232** from Group **64** to Group **128**.

At block **360**, the hub station **210** collects one or more signals representative of the demand of the remote unit **232** over the reservation channel. The hub station **210** stores the demand in an accessible memory (not shown) for later retrieval. The timing of collection of signal may not be material to the invention and, hence, may be performed before, during, or after the SNR measurement of each remote unit. For instance, the hub station **210** may collect and save the demands of all of the remote units before initiating the process of FIG. 3. At block **370**, the hub station **210** determines if the demands from all of the remote units are obtained. If the demand of more remote units is still needed, the process may return to block **310** to measure SNR of the remaining remote units and repeat the process described thus far. Alternatively, the process may return to block **360** to collect the demand of the remaining remote units over the reservation channel. In one embodiment, one or more of these steps are performed in parallel.

If, on the other hand, the demand of all of the remote units is collected, the hub station **210** determines in block **380** if one or more of the Groups **32, 64, 128** is relatively congested. This process is described in greater detail below with reference to FIG. 4. If the hub station **210** determines that no congestion is detected, the process returns to block **310** to run the entire process again. Optionally, the process may be terminated at this stage and restarted at a later time. If, on the other hand, the hub station **210** determines that one or more of the Groups **32, 64,** and **128** is congested, the process proceeds to re-allocate the frequency spectrum from the least congested (i.e., best state of performance) group to the other groups. Hence, at block **390**, the hub station **210** reduces the portion of the allocated frequency spectrum of the least congested group, and increases the portion of the allocated frequency spectrum of the other groups. This process is described in greater detail below with reference to FIG. 5. The process terminates at block **398**.

FIG. 4 is a flowchart describing the process executed in block **380** of FIG. 3 of determining the aggregate demand of one or more groups. The process begins with block **400**. As indicated above, the hub station **210** may be configured to determine relative congestion of each of the Groups **32, 64,** and **128**. At block **410**, the hub station **210** monitors the demand of a remote unit over the reservation channel. As noted above, the demand represents the amount of data (expressed in bits) that the remote unit desires to exchange or transmit at a particular instant of time. At block **420**, the hub station **210** qualifies the received demand by checking the QoS assigned to the remote unit. The hub station **210** usually stores, or has at least access to, the QoS of each remote unit operating within its coverage area. By qualifying the demand, the hub station **210** checks the QoS of the remote unit to determine whether the QoS permits allocation of resources to satisfy the entire demand or not. Pursuant to the decision block **430**, if the QoS permits satisfying the entire requested demand of the remote unit, then in block **440**, the hub station **210** takes the entire demand into consideration when assessing the aggregate demand of one of the Groups **32, 64,** and **128**. If, on the other hand, the QoS does not permit the requested demand, the hub station **210**, in block **450**, determines a reduced demand (i.e., downsizes the demand) for the remote unit, and considers the reduced demand when assessing the aggregate demand of the group.

For example, the remote unit **212** may be assigned a QoS criterion that permits it to exchange up to 32 kilobits of data per second, thereby yielding an average amount of data of 1.92 (i.e., about 2) Megabits every minute. If at 12:00:00 hours, the remote unit **212** transmits 1 Megabit, the hub station **210** checks the QoS of the remote unit **212** and determines that up to about 2 Megabits is allowed. Hence, at 12:00 hours, the hub station **210** considers the entire 1 Megabit for assessing aggregate congestion for Group **32**. If, however, at 12:00:30 hours (i.e., 30 seconds later), the remote unit **212** requests a demand to transmit 2 Megabits, the hub station **210** determines that, based on the QoS of the remote unit **212**, a demand of only about 1 Megabit is permitted for the balance of the one minute interval, i.e., during 12:00:00–12:00:01. Accordingly, for the purpose of assessing aggregate congestion for Group **32** at 12:00:30, the hub station **210** downsizes the demand from 2 Megabits to about 1 Megabit.

For each group, the hub station **210** computes the aggregate demand of the group based on the collective demand of all of the remote units within the group. Hence, at the decision block **460**, the hub station **210** checks to see if the demand was polled from all of the remote units of the group. If the demand of more remote units remains to be polled, the process returns to block **410**. If, on the other hand, the hub station **210** determines that the demand was polled from all of the remote units of the group, the process proceeds to block **470**. To determine the aggregate demand of a single group, the hub station **210**, in block **470**, adds up the demands and/or reduced demands of all of the remote units of the group. The aggregate demand represents an estimate of the (average) length of a queue of bits for the group. The hub station **210** may repeat the process for all of the Groups **32, 64,** and **128**, and stores the aggregate demand of all groups in its memory to perform congestion analysis. The process terminates in block **480**.

There are several ways to analyze congestion for each group of remote units. In one embodiment, the hub station **210** determines the congestion of each group relative to a least congested group. FIG. 5 is a flowchart describing the process of determining congestion and re-allocation of the

frequency spectrum among two or more groups of remote units. The process begins at block **500**. At block **510**, the hub station **210** identifies the least congested group, which is typically the group that has the smallest queue length. Once the least congested group is identified, the hub station **210**, in block **520**, compares the queue length of the other groups with the queue length of the least congested group. By this comparison, the hub station may compute the percentage of excess bits by dividing the queue length of a group by the queue length of the lest 1 ngested group. The percentage of excess bits represents the extent of congestion in one group relative to the least congested group. For example, the average queue length of each of Groups **32**, **64**, and **128** may be 100, 300, and 250 Megabits, respectively. In this example, Group **32** having a queue length of 100 Megabits represents the least congested group. The percentage of excess bits for Group **64** is 300% (or 300/100), and for Group **128** is 250% (or 250/100). As shown by this example, the percentage of excess bits is a number that may not be smaller than 100%, because the queue length of any group is always greater than (or equal to) the queue length of the least congested group.

At block **530**, the hub station **210** determines whether, based on the relative congestion of the groups, it is necessary to re-allocate a portion of the frequency spectrum from the least congested group to the other groups. In one embodiment, the hub station **210** bases its determination on the percentage of excess bits. For example, the hub station **210** may be configured to re-allocate the frequency spectrum only for the groups having a percentage of excess bits of 200% or greater. Hence, based on the above numerical example, the hub station **210** may remove portions of the frequency spectrum from Group **32** and assign it to Groups **64** and **128**. Accordingly, if the re-allocation of the frequency spectrum is warranted to relieve congestion, the process proceeds to block **540**. If, on the other hand, the re-allocation of the frequency spectrum is not warranted, the process terminates at block **560**.

At block **540**, the hub station **210** determines the amount of frequency spectrum (i.e., size of bandwidth) to be allocated from the least congested group to the other groups. Bandwidth commonly refers to the amount of data that can be transmitted in a given period over a transmission channel such as a radio transmitter. Typically, bandwidth is expressed in cycles per second (hertz or Hz) or bits per second (bps). It is desirable to minimize the amount bandwidth to be re-allocated from the least congested group to the other groups. By minimizing the amount of re-allocated bandwidth, the probability of queue oscillation and, hence, system instability is reduced. Queue oscillation commonly refers to the transfer of congestion between a least congested group and other groups back and forth, i.e., in an oscillating manner.

To minimize queue oscillation, it is desirable to re-allocate the bandwidth in a stepwise fashion from the least congested group to the other groups. In one embodiment, using the stepwise fashion, the hub station **210** may re-allocate bandwidth in unit increments to the higher congested groups. For example, using the above numerical example, the hub station **210** may re-allocate a bandwidth of 64 kbps from Group **32** to Group **64**, and a bandwidth of 128 kbps from Group **32** to Group **128**. The purpose of re-allocating the bandwidth is to relieve congestion in the groups having greater congestion. Accordingly, at block **550**, the hub station **210** re-allocates portions of the frequency spectrum from the least congested group to the other groups. The re-allocation process terminates at block **560**.

In one embodiment, the hub station **210** continuously, or during predetermined time intervals, repeats the process of FIG. **5**. The relief of congestion in the other groups may increase likelihood of congestion in the least congested group. However, the ability of the hub station **210** to continuously monitor group congestion, and re-distribute the assigned frequency spectrum among the groups of remote units, reduces the likelihood of congestion in a single group. Moreover, the continuous monitoring and re-allocation of the frequency spectrum optimizes frequency utilization among the remote units.

FIG. **6** is a table showing exemplary groups of the remote units of FIG. **2**. As noted above, the hub station **210** assigns each remote unit to a camp or group based on the data rate assigned to each remote unit. In the table **600**, the hub station **210** assigns a data rate of 32 kbps to remote units **212**–**224** and **244**–**246** and, thus, these remote units belong to Group **32**. Similarly, the hub station **210** assigns a data rate of 64 kbps to remote units **232**–**242** and, thus, these remote units belong to Group **64**. Finally, the hub station **210** assigns a data rate of 128 kbps to remote units **252**–**270** and, thus, these remote units belong to Group **128**. As noted above, the data rate is generally assigned to each remote unit based on its channel performance, e.g., the measured SNR of the signals transmitted from each remote unit and received at the hub station **210**. As explained above, if the SNR falls within an optimal range, the currently assigned data rate of the remote unit is maintained. If the SNR falls below a low or above a high threshold value, the data rate of the remote unit is reduced or increased accordingly. The hub station **210** maintains the table **600** in memory, or within easy access, to keep track of and update each group of remote units.

FIG. **7** is a table showing an exemplary change in the Groups **32**, **64**, and **128**. In this embodiment, the table **700** shows that the remote units **244** and **246** no longer belong to Group **32**, but now belong to Group **64**. Typically, a change in the grouping of the remote units **244** and **246** indicates that the measured SNR of the channel of each of the remote units **244** and **246** falls above the high threshold value. In that case, the hub station **210** instructs the remote units **244** and **246** to increase their respective data rates from 32 to 64 kbps. Accordingly, the hub station **210** updates the table **600** to the table **700**, which shows that the remote units **244** and **246** belong to Group **64**.

FIG. **8** is a graphical representation of the process of re-allocating the frequency spectrum among the remote units as a function of frequency and time. The graph **800** includes a vertical axis that represents the portions of the frequency spectrum (e.g., bandwidth) assigned to each group. More particularly, the graph **800** shows that the bandwidth **832** is assigned to Group **32**, bandwidth **864** is assigned to Group **64**, and bandwidth **828** is assigned to Group **128**. The graph **800** also includes a horizontal axis that represents the time domain T. Beginning at T=0, the graph **800** shows that the time interval during which each remote unit may communicate is represented by a box (or timeslot) marked by the remote unit number.

For example, during the time interval 0–t_3, the graph **800** shows that the remote unit **212** is allocated a timeslot **212** and carrier frequency F_8, and is operating in Group **32** at a data rate of 32 kbps. During the same time interval 0–t_3, the graph **800** shows that the remote unit **214** is allocated the timeslot **214** and carrier frequency F_7, and is operating in Group **32** at a data rate of 32 kbps. During the time interval 0–t_2, the graph **800** shows that the unit **232** is allocated a timeslot **232** and carrier frequency F_9, and is operating in Group **64** at a data rate of 64 kbps. During the time interval

$0-t_3$, the graph 800 shows that the remote unit 252 is allocated a timeslot 252 and carrier frequency F_{10}, and is operating in Group 128 at a data rate of 128 kbps.

In this embodiment, it can be seen that the duration of the timeslot for the remote units of Group 32 is twice as long as the timeslot for the remote units of Group 64, and four times as long as the timeslot for the remote units of Group 128. The relationship between the duration of the timeslots among the various groups is typically a function of the assigned data rate. For example, because the data rate of 64 kbps is twice the data rate of 32 kbps, it is expected that the duration of the timeslot of Group 64 will be half the duration of the timeslot of Group 32. This timeslot/frequency structure simplifies the implementation of TDMA and FDMA systems having various operating data rates. Finally, it can also be seen that, in all of the groups, each remote unit does not occupy more than a single timeslot concurrently. The occupation of a single timeslot simplifies the operation of single-channel transceiver systems. Once the portion of the frequency spectrum for each group is determined, the hub station 210 may assign one or more timeslot/frequency to a particular remote unit (within a group) using any standard implemented in the hub station 210. Additional details concerning the transmission of channel assignment information to a plurality of remote units are disclosed in assignee's application entitled SYSTEM AND METHOD FOR EFFICIENT CHANNEL ASSIGNMENT, application Ser. No. 09/407,640, filed Sep. 28, 1999, now U.S. Pat. No. 6,532,220, the entirety of which is hereby incorporated by reference. The invention is not limited to only such systems, but may be implemented using any timeslot/frequency structure that is compatible with the characteristics of the invention.

The graph 800 illustrates an exemplary change in respective bandwidth among the groups in response to the hub station's decision to re-allocate the assigned frequency spectrum. As shown in FIG. 8, at time $T=t_4$, the hub station 210 changes the frequency spectrum allocation among the groups of remote units. More particularly, the graph 800 shows that each of the bandwidths 828 and 864 is doubled in size, and the bandwidth 832 is reduced accordingly. Hence, instead of availing only a single timeslot to Group 128 before $T=t_4$, two concurrent timeslots are available to the remote units of Group 128 after $T=t_4$. For example, as of time $T=t_4$, it can be seen that the remote units 270 and 268 are concurrently communicating at an assigned data rate of 128 kbps (Bandwidth 828). Similarly, instead of availing only a single timeslot to Group 64 before $T=t_4$, two concurrent timeslots are available to the remote units of Group 64 after $T=t_4$. For example, as of time $T=t_4$, it can be seen that the remote units 240 and 242 are concurrently communicating at an assigned data rate of 64 kbps (Bandwidth 864). On the other hand, instead of availing eight concurrent timeslots to Group 32 before $T=t_4$, only two concurrent timeslots remain available to the remote units of Group 32 after $T=t_4$. This illustration shows that, in response to the relative congestion of each of the Groups 64 and 128, the hub station 210 has determined that such congestion warrants frequency re-allocation from the least congested Group 32 to Groups 64 and 128, as explained in detail above.

Furthermore, the graph 800 illustrates an exemplary change in the data rate of one or more remote units. As shown in FIG. 8, it can be seen that before $T=t_5$, each of the remote units 244 and 246 was operating in Group 32 (Bandwidth 832) at a data rate of 32 kbps, as shown by timeslots 244 and 246 of Group 32. After time $T=t_5$, however, the remote units 244 and 246 are operating in Group 64 (Bandwidth 864) at a data rate of 64 kbps, as shown by timeslots 244 and 246 of Group 64. Hence, the graph 800 demonstrates that, sometime during the interval t_4-t_5, the hub station 210 determined to change the assigned data rate of remote units 244 and 246 from 32 to 64 kbps. As explained in detail above, the hub station 210 bases its determination on the measured SNR for the channel of each of the remote units 244 and 246. In this example, the SNR falls above a high threshold value (e.g., 11 dB), thereby warranting an increase in data rate. Accordingly, the hub station 210 instructs the remote units 244 and 246 to raise their respective data rates.

In another embodiment of the invention, the reverse link resources are not pre-assigned to particular camps of remote units. FIG. 9 is an exemplary graphical representation of the three quality of service operating regions for a particular remote unit, e.g., remote unit 212 (see FIG. 2) which operates in such an environment. As noted above, the QoS is typically allocated to each remote unit pursuant to a subscription agreement between the remote unit and the service provider. Independent of the assigned data rate, the QoS specifies an allocated average data rate. While the assigned data rate specifies the rate at which the remote unit is capable of transmitting information over the channel when the remote unit is allocated a resource, the allocated average data rate reflects the average data rate over some extended period which the remote unit has, for example, purchased from the service provider. For example, if a remote unit has an assigned data rate of 256 kbps and an allocated average data rate of 32 kbps, although the remote unit transmits in bursts at a rate of 256 kbps, the bursts are dispersed in time by idle periods which reduce the average data transfer rate of the remote unit to about 32 kbps. In other words, the average duty cycle of this remote unit's transmission is at most about one-to-eight.

FIG. 9 shows a vertical axis 402 representing a range of current average data rates for the remote unit 212. Pursuant to its agreement, the remote unit 212 has subscribed for an allocated average data rate 404 (e.g., 32 kbps). Average data rates below this value are represented by an IN region 406. In one embodiment, it may be desirable to allow the remote unit 212 to exceed its allocated average data rate 404, and permit operation in an OUT region 414. The OUT region 414 represents a range of average data rates at which the remote unit 212 may operate above its allocated average data rate 404. Hence, the OUT region 414 represents average data rates ranging from the allocated average data rate 404 to a maximum average data rate 408 (e.g., 48 kbps). As further shown in FIG. 9, a HARD DROP region 412 represents average data rates above the maximum average data rate 408.

In one embodiment, the allocated average data rate 404 is associated with a particular remote unit in accordance with a subscription agreement between the remote unit operator and the owner/operator of the hub station. For example, a service provider may wish to reduce the operating costs associated with providing Internet services by purchasing a relatively low allocated average data rate 404. As the number of subscribers and the demand on the system increases, the service provider may purchase a higher allocated average data rate 404, presumably at a greater cost.

The quality of service levels 404 associated with remote units are stored by hub station. In one embodiment, the hub station includes tables that store a remote unit identifier and an associated allocated average data rate 404. In one

embodiment, the tables are updated by the hub station operator when subscription information is added or modified.

Each hub station stores a range parameter that is used to define the data rate by which a transmission from a remote unit can exceed the allocated average data rate **404**. The range parameter defines the size of the OUT region **414** by providing the value for the maximum average data rate **408**. The range parameter may be selected based on typical system use, the capacity of the hub station, and other factors. The use of the maximum average data rate artificially limits the average data rate of a remote unit even if system resources are available, thus encouraging the purchase of a higher allocated average data rate. In other embodiments, the same mechanisms may be employed to limit the maximum average data rate pursuant to other motives.

In this embodiment, the invention provides a method and system of scheduling remote unit communications of the system **200** within the available communication resources. As noted above, the hub station **210** may continuously receive demand of each of the remote units over the reservation channel. In this embodiment, the hub station **210** arranges each arriving demand in a queue on a first in first out (FIFO) basis.

In one embodiment, the hub station **210** categorizes or classifies each remote unit demand based, at least in part, on the current average data rate for the remote unit over some previous period of time. As indicated above, the hub station **210** may compute a current average data rate based on a moving average over a predetermined time interval (e.g., 10, 30, 60 seconds, or other desired interval). The moving average is determined by dividing the amount of data transmitted during a predetermined past time interval by the predetermined time interval.

For example, assume that a remote unit has an allocated average data rate of 48 kbps, a maximum average data rate of 60 kbps and that the hub station uses a predetermined time interval of 60 seconds for determining the remote unit's average data rate. Further, assume that, after a long period of idleness, at 12:00:01, the remote unit **212** completes a transfer of 1 Megabit of data. Hence, up to 12:00:02, the current average data rate of the remote unit is about 17 kbps (i.e., 1 Megabit/60 seconds), which places the remote unit **212** in the IN region **406**. At 12:00:30 hours, the remote unit **212** completes the transfer of 2 Megabits of data. In view of the 1 and 2 Megabit transfers, the current average data rate of the remote unit **212** at time 12:00:31 is 50 kbps (3 Megabits/60 seconds), which places the remote unit's **212** operating point in the OUT region **414**. Finally, if at 12:00:45, the remote unit **212** completes the transfers of 3 Megabits of data, the current average data rate of the remote unit **212** at time 12:00:46 is about 100 kbps (i.e., 6 Megabits/60 seconds), which places the remote unit's operating point in the DROP HARD region **412**. If, as time continues to pass, the remote unit **212** does not transfer any more data, the remote unit's current average data rate eventually falls through the OUT region **414** and into the IN region **406**.

FIG. **10** is a flowchart describing a second embodiment of the process of dynamically scheduling remote unit communications. The process begins at start block **804**. As noted above, in one embodiment, the hub station **210** receives demand requests from each remote unit that desires to communicate data over the system **200** (see FIG. 2) and places a corresponding entry in a FIFO queue. At block **808**, the hub station **210** determines the current average data of the first remote unit corresponding to the first entry in the FIFO queue, for example, as just described.

At block **812**, the hub station **210** determines if the current average data rate of the remote unit **212** classifies it as operating in the HARD DROP region **412** (see FIG. 9). If, based on the amount of data transmitted by this remote unit over the predetermined interval (e.g., past 60 seconds), the remote unit **212** is operating in the HARD DROP region **412**, the process proceeds to block **816** where the hub station **210** places the current demand entry to the end in the FIFO queue. By delaying satisfaction of the demand to a later time, the hub station **210** declines to grant a bandwidth/timeslot to the remote unit **212** at this time thereby reducing the current average data rate of the remote unit moving forward in time. In another embodiment, the demand entry is removed from queue and is not replaced with in the queue.

If, on the other hand, the remote unit **212** is not operating in the HARD DROP region **412** during the predetermined interval, the process proceeds to block **820** where the hub station **210** determines if the remote unit **212** is operating in the OUT region **414**.

If, based on its current average data rate over the predetermined interval, the remote unit **212** is operating in the OUT region **414**, the process continues to block **824** where the hub station **210** performs the OUT version of a pair of algorithms, such as Random Early Drop (RED) with In/Out bit (RIO). In one embodiment, the RED and RIO algorithms are executed by a gateway within the hub station. Generally, a RED algorithm computes the average queue length and, when the average queue length exceeds a certain dropping threshold, the gateway begins to randomly drop demand requests with a certain probability, where the exact probability is a function of the queue length at the hub stations.

If, based on its current average data rate over the predetermined interval, the remote unit **212** is operating in the IN region **406**, the process continues to block **828** in which a second Random Early Drop (RED) algorithm is performed. Typically, the dropping threshold reflects a longer queue length for the IN packets than the OUT packets and the probability of dropping an OUT packet is higher than or equal to the probability of dropping an IN packet over the entire range of queue lengths. For further details on the RED and RIO algorithms and gateways, reference is made to Clark, D. and Fang, W., Explicit Allocation of Best Effort Packet Delivery Service, which is available via http://diff-serv.lcs.mit.edu/Papers/exp-alloc-ddc-wf.pdf.

If the demand request is not passed (i.e., is dropped) by the RED algorithm in either block **824** or **828**, the process returns to block **816** where the hub station **210** places the demand entry at the end of the FIFO queue or drops the request from the FIFO queue. If, on the other hand, the demand request of the remote unit **212** is passed by the RED algorithm in either block **824** or **828**, the process continues to block **830**.

In block **830**, the hub station **210** schedules the remote unit communication. More particularly, to schedule the remote unit communication, the hub station **210** determines the bandwidth that is commensurate with the assigned data rate of the remote unit **212**. Based on the assigned data rate, the hub station **210** determines the next time T at which such bandwidth is available (i.e., not already scheduled to another remote unit transmission) over a time period which allows the remote unit **212** to exchange the desired amount of data. In this embodiment, the assigned data rate preferably remains at the highest rate or rate group possible for the remote unit to adequately transfer data.

At block **834**, the hub station **210** determines if a next demand entry is in the FIFO queue waiting to be scheduled. In one embodiment, the process of FIG. **10** runs continu-

9. The method of claim 4, wherein determining relative data congestion of the group of transmitters includes identifying the group with the smallest length of data queue.

10. The method of claim 9, wherein allocating at least a portion of the RF spectrum includes assigning a portion of the RF spectrum from the group of transmitters having the smallest length of data queue to at least one other RF transmitter.

11. The method of claim 4, further comprising comparing length of data queue of the group of transmitters with length of data queue of another group of transmitters.

12. The method of claim 4, further comprising monitoring demand of at least one other group of transmitters within the plurality of RF transmitters, the group comprising at least one RF transmitter.

13. A communication receiver that receives radio frequency (RF) signals from a plurality of RF transmitters, the communication receiver accessing a processor that is programmed with instructions that when executed perform a method comprising:

monitoring demand of a group of transmitters within the plurality of RF transmitters, the group comprising at least one RF transmitter;

determining, in response to the monitored demand, relative data congestion of the group of transmitters; and

allocating at least a portion of the RF spectrum from a group having a least amount of congestion to at least one other RF transmitter.

14. The receiver of claim 13, wherein the method further comprises adjusting demand of each of the transmitters of the group based, at least in part, on quality of service of each of the transmitters of the group.

15. The receiver of claim 14, wherein adjusting demand of each of the transmitters of the group includes granting at least a portion of the demand of each of the transmitters of the group.

16. The receiver of claim 15, wherein the method further comprises determining aggregate demand of the group based, at least in part, on the adjusted demand of each of the transmitters of the group.

17. The receiver of claim 13, wherein monitoring demand of the group of transmitters includes receiving information representing the amount of data that each of the transmitters of the group requests to exchange.

18. The receiver of claim 13, wherein determining relative data congestion of the group of transmitters includes identifying the group with the smallest length of data queue.

19. The receiver of claim 18, wherein allocating at least a portion of the RF spectrum includes assigning a portion of the RF spectrum from the group of transmitters having the smallest length of data queue to at least one other RF transmitter.

20. The receiver of claim 13, wherein the method further comprises comparing length of data queue of the group of transmitters with length of data queue of another group of transmitters.

21. The receiver of claim 13, wherein the method further comprises monitoring demand of at least one other group of transmitters within the plurality of RF transmitters, the group comprising at least one RF transmitter.

22. A system for allocating at least a portion of the radio frequency (RF) spectrum among a plurality of RF transmitters, the system comprising:

a plurality of RF transmitters each configured to transmit data representing respective demand to communicate data; and

a receiver in communication with the plurality of RF transmitters, the receiver being configured to monitor the demand of a group within the plurality of RF transmitters, the group comprising at least one RF transmitter, wherein the receiver is further configured to re-allocate a portion of the RF spectrum from the group of RF transmitters having smallest demand to at least one other RF transmitter, wherein each RF transmitter is configured to periodically transmit data representing the respective demand to the receiver over a dedicated RF channel.

23. The system of claim 22, wherein the receiver is configured to measure a signal-to-noise ratio of the dedicated RF channel of at least one of the plurality of RF transmitters and assign an increased data rate to the at least one of the plurality of RF transmitters in the event that the measured signal-to-noise ratio is above a predetermined threshold.

24. The system of claim 22, wherein the receiver is configured to measure a signal-to-noise ratio of the dedicated RF channel of at least one of the plurality of RF transmitters and assign a reduced data rate to the at least one of the plurality of RF transmitters in the event that the measured signal-to-noise ratio is below a predetermined threshold.

25. The system of claim 22, wherein the receiver is configured to measure a signal-to-noise ratio of the dedicated RF channel of at least one of the plurality of RF transmitters and maintain a currently assigned data rate for the at least one of the plurality of RF transmitters in the event that the measured signal-to-noise ratio is within a predetermined range.

26. The system of claim 22, wherein the receiver is configured to reallocate 1 e portion of the RF spectrum in a stepwise manner by a predetermined amount of bandwidth.

27. A communication system programmed with instructions that when executed by a processor perform a method of assigning at least a portion of the radio frequency (RF) spectrum among at least one of a plurality of RF transmitters and RF receivers, the method comprising:

monitoring a communication parameter that relates to performance of a group within the plurality of RF transmitters and receivers, the group comprising at least one of the plurality of RF transmitters and receivers;

determining, in response to the monitored communication parameter, a state of performance of the group; and

allocating at least a portion of the RF spectrum from the group having best state of performance to at least one of the plurality of RF transmitters and receivers, wherein determining the state of performance of the group includes determining length of data queue of the group.

28. A system for allocating at least a portion of the radio frequency (RF) spectrum among a plurality of RF transmitters, the system comprising:

means for monitoring demand of a group of transmitters within the plurality of RF transmitters, the group comprising at least one RF transmitter;

means for determining, in response to the monitored demand, relative data congestion of the group of transmitters; and

means for allocating at least a portion of the RF spectrum from the group having least amount of congestion to at least one other RF transmitter.

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29. A method of assigning a portion of the radio frequency (RF) spectrum among a plurality of transmitters, the method comprising:

monitoring demand of at least first and second groups of transmitters, the first group operating at an average data rate that is different than the data rate of the second group of transmitters;

adjusting the demand of each of the at least first and second groups of transmitters based at least in part on a quality of service that is commensurate with each transmitter of the first and second groups of transmitters;

determining, based at least in part on the adjusted demand, the group of transmitters that is least congested;

reducing the size of RF bandwidth that is assigned to the least congested group of transmitters; and

increasing the size of RF bandwidth that is assigned to the other group of transmitters.

30. The method as defined in claim 29, wherein determining the group of transmitters that is least congested includes identifying the group of transmitters that has the smallest data queue.

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